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ABSTRACT

This paper describes the development of the hardware-software configuration required for a computerized digitizer-graphics system for encoding locational information at the University of Iowa's Department of Geography and Institute of Urban and Regional Research. Topics covered include system requirements, data structure, hardware configurations, and the development of software to interface the digitizer and an IMLAC PDS-4 minicomputer with a host HP-2000 computer. Problem areas are identified in user documentation, operating efficiency, system support, budgetary, testing, and transportability. (RAO)

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INTERACTIVE DIGITIZING AND GRAPHICS: EDUCATIONAL DEVELOPMENTS AND APPLICATIONS

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INTERACTIVE DIGITIZING AND GRAPHICS: EDUCATIONAL DEVELOPMENTS AND APPLICATIONS

INTRODUCTION

In 1976 the University of Iowa's Department of Geography and Institute of Urban and Regional Research undertook the design of a digitizer-graphics system which would meet a growing need on campus for a modern means of encoding locational information. It was reasoned that if the system were flexible enough, educators and researchers alike could take advantage of it. This paper will describe the development of this hardware-software configuration which, despite some enduring problems, is today enjoying considerable success. The developments made also demonstrate how an interactive environment can tackle many sophisticated data encoding and analysis problems previously available only in batch and yet is versatile enough to be or use in classroom projects. Digitized files can be created, stored, edited, and scaled in a number of ways. Certain educational applications have been made possible by linking these digitized files with data bases, thereby allowing students to scrutinize base maps and visual representations of data. Other applications serve broad research pursuits by

providing outputs suitable for many pre-programmed mapping and geographic information systems. Users with the requisite programming experience may also write their own application programs which draw on digitized data produced by the host interactive digitizing and application software.

PROBLEM ENVIRONMENT

The initial requirements of the digitizer-graphics system were:

- Fast and accurate digitizing. The user should at least be able to get punched card output of digitized coordinates.
- Graphics monitoring and hard copy of the digitized image on the CRT.
- Digitized file storage, editing, and expansion. By recording the digitized coordinates on a disk file, the user should be able to display what has previously been digitized and, using the monitor, be able to interactively edit and expand his files. Editing should include the capacity to insert new coordinates, and move or delete old ones.
- Analysis of digitized and relational data bases. Besides performing relatively routine tasks, such as computing areas and distances, the system should be capable of relating digitized data with multivariate geographic data.

These requirements dictated an interactive hardware-software environment with a refresh CRT so that digitized data could be displayed on the screen and be visually addressable for editing. A minicomputer could fill many of these needs, but a larger interactive host computer would have to handle storage and data manipulation. Interchangeable point, line, area, and label data structures were formulated, allowing the development of more versatile analysis routines than were originally planned.

DATA STRUCTURE

Several forms of convertible data and file structures have been devised. Coordinates from the digitizer are formatted by the minicomputer and the host into "digitized files" which store any combination of four types of graphic "elements": (1) labeled or unlabeled points, (2) labeled or unlabeled lines, (3) labeled areas, and (4) text. Coordinates, or "atoms", within each element share the same attributes, including label and symbol size and intensity. By varying these attributes, almost any type of map can be digitized. Figure 1 shows a schematic of digitized file structure, including the programs for editing and converting it from one file structure to another.

The significance of the digitized file structure to users is that it can be used for a wide range of applications that require generalized representation of points, lines or areas, such as in computer mapping and general locational and network

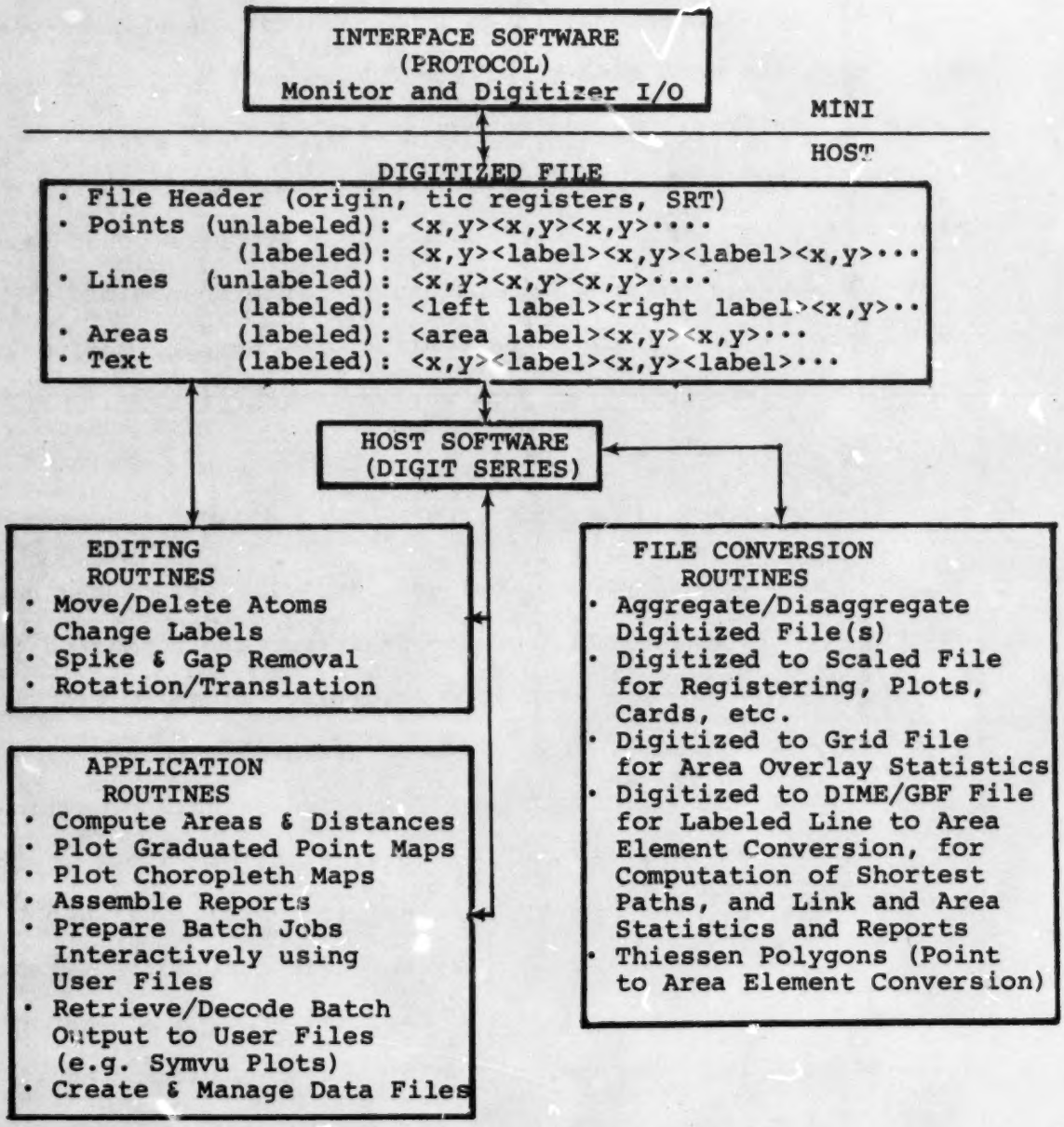
INTERFACE SOFTWARE
(PROTOCOL)
Monitor and Digitizer I/O
MINI
HOST
DIGITIZED FILE
• File Header (origin, tic registers, SRT)
• Points (unlabeled): <x,y><x,y><x,y>····
(labeled): <x,y><label><x,y><label><x,y>···
• Lines (unlabeled): <x,y><x,y><x,y>····
(labeled): <left label><right label><x,y>··
• Areas (labeled): <area label><x,y><x,y>···
• Text (labeled): <x,y><label><x,y><label>···
HOST SOFTWARE
(DIGIT SERIES)
EDITING
ROUTINES
• Move/Delete Atoms
• Change Labels
• Spike & Gap Removal
• Rotation/Translation
APPLICATION
ROUTINES
• Compute Areas & Distances
• Plot Graduated Point Maps
• Plot Choropleth Maps
• Assemble Reports
• Prepare Batch Jobs Interactively using User Files
• Retrieve/Decode Batch Output to User Files (e.g. Symvu Plots)
• Create & Manage Data Files
FILE CONVERSION
ROUTINES
• Aggregate/Disaggregate Digitized File(s)
• Digitized to Scaled File for Registering, Plots, Cards, etc.
• Digitized to Grid File for Area Overlay Statistics
• Digitized to DIME/GBF File for Labeled Line to Area Element Conversion, for Computation of Shortest Paths, and Link and Area Statistics and Reports
• Thiessen Polygons (Point to Area Element Conversion)

Figure 1. Digitized File and Software Configuration.

analyses. Figure 1 illustrates the ability to convert digitized files into topological and grid files. Digitized files can be translated to DIME files, scaled files, and grid files. DIME and scaled files, in turn, can be converted into digitized files. Digitized files are translated into a grid file using a raster scanning technique (Dueker, et al., 1977). This interchangeability therefore allows additional applications after conversion of network to area data, or conversion of area to grid data.

HARDWARE CONFIGURATION

The hardware configuration makes possible the use of a large variety of storage media for digitized files and has the capacity for generating several different kinds of plots. The hardware system illustrated in Figure 2 shows the interconnection of three computers -- the intellegent terminal for digitizing and graphics, the host interactive minicomputer, and the IBM360/65 for batch processing. Important portions of the system are the Science Accessories Corporation GRAF/PEN sonic digitizer, a refresh CRT with a 2048 × 2048 displayable raster, and the IMLAC Corporation photoelectric hardcopier, push button menu pad, and keyboard. But the most crucial portion of the system lies in the interface between the 24K byte memory IMLAC PDS-4 minicomputer and the host HP-2000 time-sharing computer. A major portion of the host software and user-generated files resides on an on-line disk controlled by the HP-2000. An SRT (scale, rotate, and translate) hardware

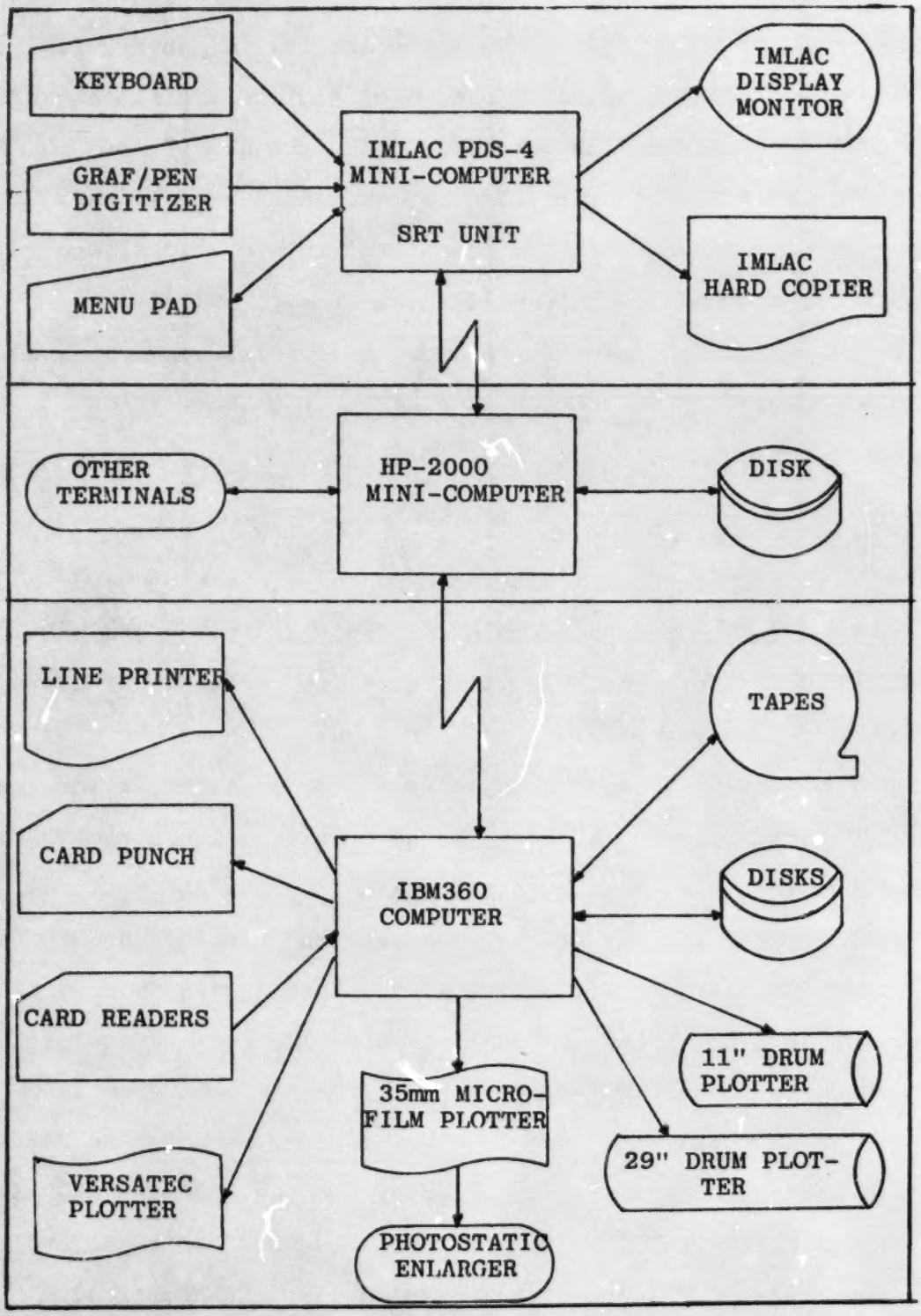

Figure 2. Hardware Configuration.

unit has also been added to the PDS-4, allowing almost complete visual control over the display.

The digitizer hardware includes a 48 inch sonic digitizer, consisting of two perpendicular banks of microphones mounted on a drafting table. The user traces the figures to be encoded with a stylus which emits a high frequency tone when pressed. The stylus and microphones are connected to the GRAF/PEN conbrol box which calculates the position of the stylus on the drafting table. The digitizer coordinate system is composed of a 4095 × 4095 grid with one "digitizer unit" corresponding to approximately 1/85 inch: a resolution high enough for statistical mapping and analysis projects, but inadequate for some cartographic applications. Interface software between the PDS-4 and HP-2000 formats digitized coordinates into point, line, area, and text elements for subsequent processing by the host software. The digitized elements are displayed on the monitor screen and stored by the host as a digitized file.

After the digitized file has been created, it can be edited, converted to other file structures, and used as input to various application programs. For example, the link between the HP-2000 and the IBM360 computers permits access in batch mode to drum plotters, a microfilm plotter, a Versatec plotter, tape drives, card punches, disk packs, lineprinters, and IBM360 programs. Other software on an IBM360 disk allows

the use of "canned programs" such as Coplot, Symap, and Symvu. The output from these programs can then be retrieved by the HP-2000 and converted to digitized files for display on the PDS-4 and for building other digitized files. The user can also send coordinates from cards or tape to the HP-2000 and the PDS-4 to create digitized files from a FORTRAN program.

SOFTWARE CONTROL

Two sets of software were developed to handle the stated needs. The first group, called PROTOCOL, interfaces the digitizer and IMLAC PDS-4 minicomputer with the host HP-2000 computer. PROTOCOL was written by Robert Werner and James Ingrahm of the University of Iowa Computer Center. These machine language programs are transparent to the host software and consume 8K of IMLAC program memory. The remaining 16K memory is used for the refresh display.

A second set of software, called the DIGIT SERIES, comprises over 60 chained programs and is written in HP BASIC. HP BASIC is well-suited for interactive program control, direct access file creation and I/O, and for the manipulation of ASCII string data sent from and received by PROTOCOL. DIGIT software addresses most of the other needs and is entirely a host software package. Access to all the routines is made from one which logs the user into the DIGIT SERIES, prints messages that have been written by previous users or the system manager, and displays the central option list shown in Figure 3.

FIGURE 3. DIGIT SERIES MAJOR OPTION LIST.

```
(1) CREATE/DISPLAY A DIGITIZED FILE
(2) EDIT A DIGITIZED FILE
(3) TRANSLATE DIGITIZED FILE TO SCALED FILE
(4) TRANSLATED SCALED FILE TO DIGITIZED FILE
(5) JOIN DIGITIZED FILE(S)
(6) STORE A SCALED FILE
(7) CREATE/DISPLAY A STATISTICAL POINT MAP
(8) PUNCH SCALED COORDINATES ONTO CARDS/DISK/TAPE
(9) PLOT SCALED COORDINATES USING CALCOMP/VERSATIC PLOTTER
(10) PLOT USING SYMAP/SYMVU
(11) FIND MAP AREAS
(12) FIND MAP DISTANCES
(13) FILE UTILITIES
(14) SPECIAL APPLICATIONS (THIESSEN, CHORO, QUADRAT, DIME)
(15) LOGIN OPTIONS
(16) IBM360 FILE UTLITIES
(17) COPLOT
(18) GEOGRAPHIC INFORMATION SYSTEMS (INFOS)
(19) STOP
(20) SIGN-OFF

     ENTER OPTION NUMBER >
```

This same list of options is displayed after completing each application program. Besides creating, editing, displaying, and scaling a digitized map, the DIGIT SERIES also provides options to join contiguous coordinates (to remove spikes and gaps); to compute areas, perimeters, and distances between points on a map or diagram; to convert from one file structure to another and generate associated statistics and reports; to produce choropleth and statistical point maps; and perform other useful analyses. Most of the programs give the user the opportunity to view a detailed description which explains what the program does and which algorithms are used. The programs then present the user with easily understood options in the

form of either yes/no or multiple choice questions. Figure 3 shows the first of several levels of option lists. FILE UTILITIES, for example, has 19 suboptions. This hierarchical option structure allows users to focus in on the intended application without having to perform redundant or superfluous analyses.

Figures 4 and 5 show how a digitized file, when combined with locational data files, allows students to produce graduated circle and choropleth maps. As is seen in Figure 4 of a student's project, a digitized file containing his base map has been overlayed with graduated point symbols according to the locations provided by a digitized DATA POINTS file and using data from a DATA VALUES file. These same files can be submitted to Symap and other pre-programmed mapping routines. The DATA VALUES file can contain multivariate geographic data which can be used in their raw form or scaled in a number of ways.

Figure 5 shows another student's project which was generated by the DIME program. Each enumeration district in Cedar Rapids, Iowa was digitized using labeled line elements. Using data supplied by a Geographic Base File (GBF), the user requested creation of area elements of 30 census tracts. The choropleth mapping program CHORO supplied the shading according to corresponding census data. With DIGIT it is easy for untrained personnel to assemble a small area geographic information

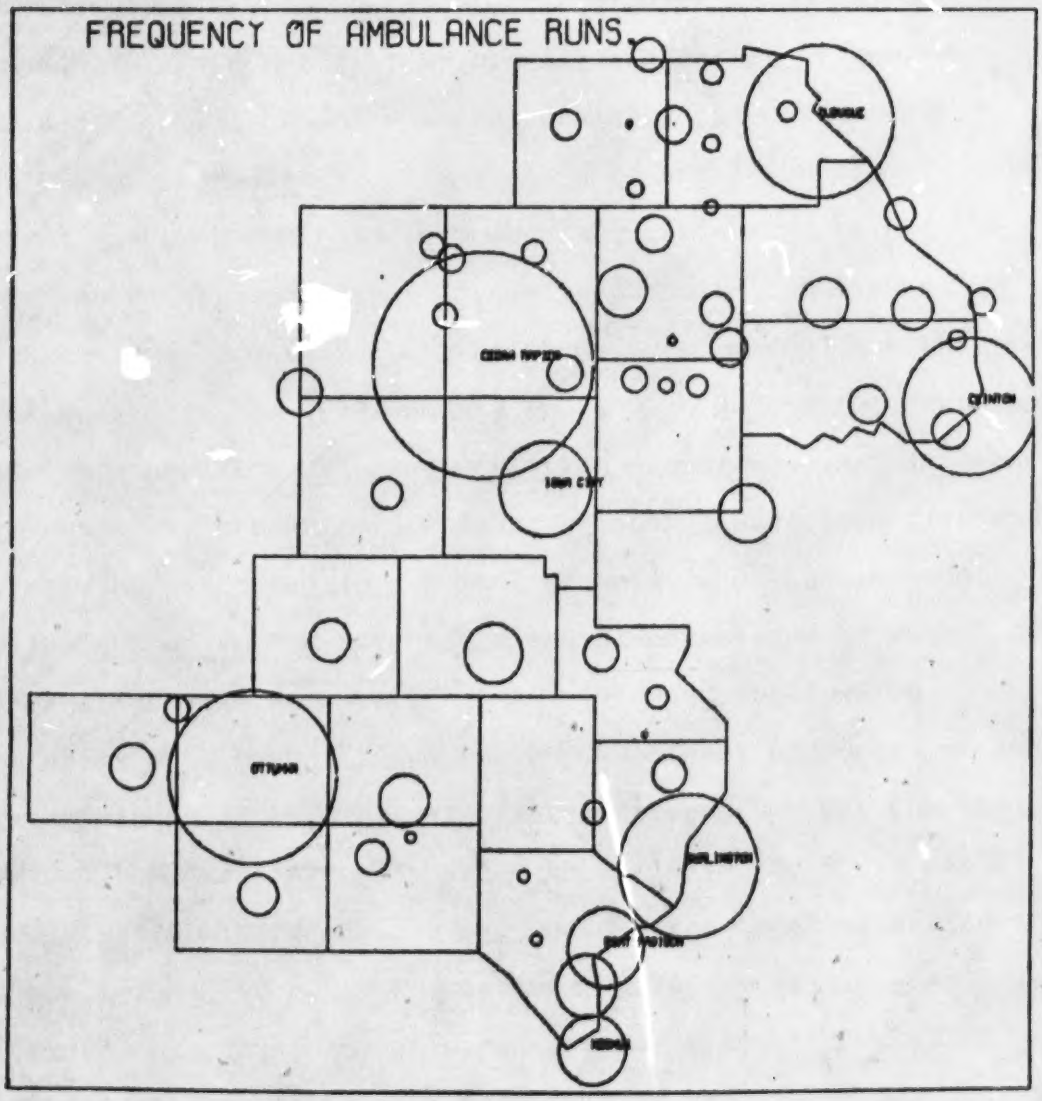

Figure 4. Example of Graduated Circle Plot.

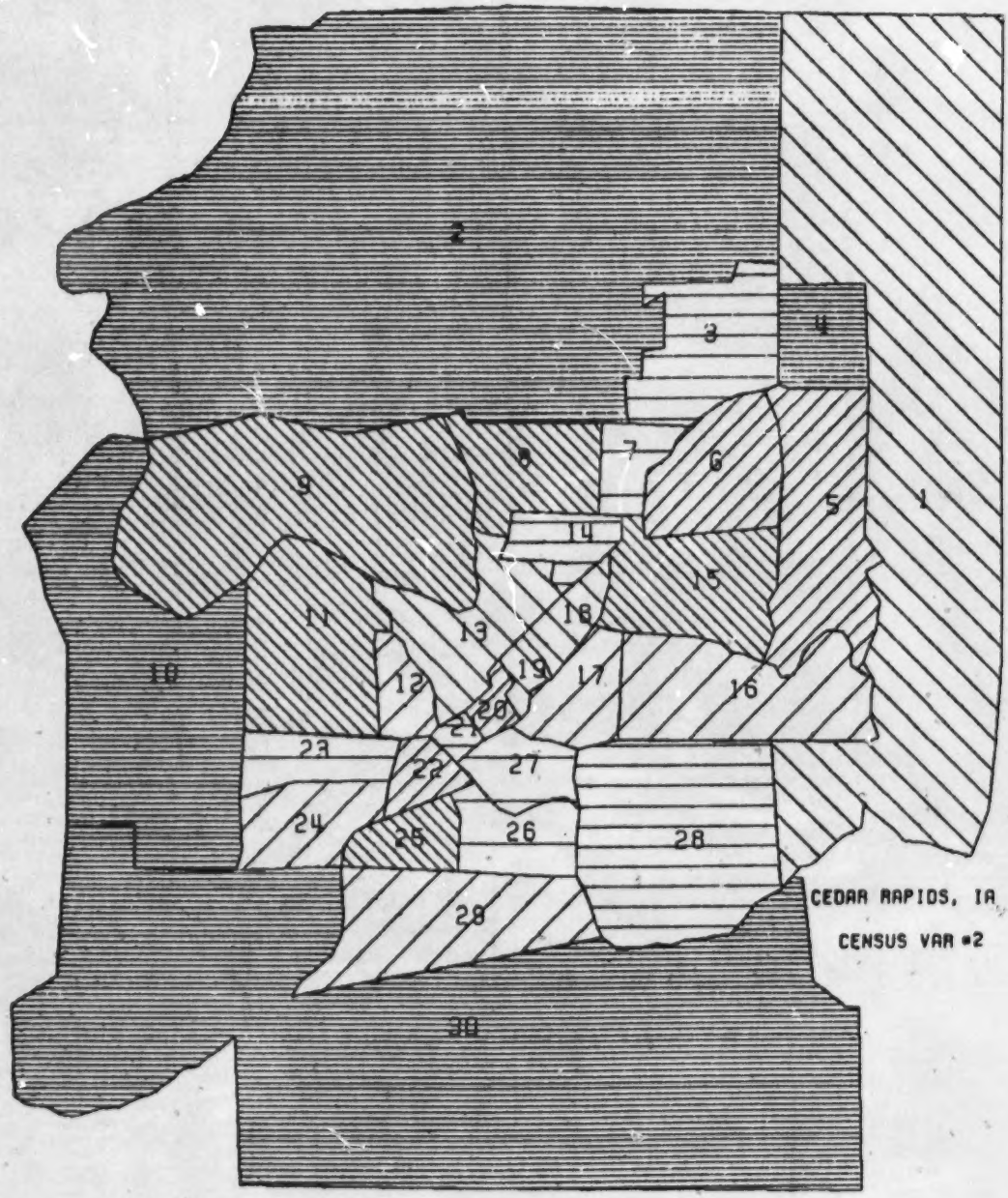

Figure 5. Example of Output from DIME and CHORO. (CHORO was programmed by Edward Hillsman, Dept. of Geography, University of Iowa).

system to suit a particular region or need (Dueker, 1977)

EVIDENCE OF SUCCESS

In the past two years over 150 users have operated the graphics system, including researchers from a variety of disciplines: Geography, Urban and Regional Planning, Art, Engineering, Geology, Men's Physical Education, Sociology, Anthropology, Theater, and the University's Institute of Urban and Regional Research and Health Services Research Center. Access to the system has also been requested by federal, state, and local agencies.

Classroom usage has been as successful as research applications. New students are continually being trained to use the system as a part of their class projects. For example, the Department of Geography's introductory cartography class and students in an urban and regional planning course have used the graduated circle and choropleth mapping packages to compare census tract variables. In addition, a graduate course in geographic statistics used the QUADRAT program to analyze digitized point patterns. In another graduate course, students have been taught to use the recently introduced INFOS program to find areal statistics of land use maps. The skills and concepts learned by these students can be applied to a number of geoprocessing problems.

ENDURING PROBLEMS

The success of the graphics system demonstrates how the normally complex, technical process of digitizing can be reduced in its complexity by providing a series of well-explained options which even inexperienced student users can choose successfully. Thus students are freed from learning a programming or command language, and terminal time can be devoted to more creative pursuits. But even with these successes several problems have emerged. With continual software development, and a high demand for terminal time, the need for user documentation has grown. As has been demonstrated, preparation and analysis of a digitized file can usually be performed in a number of ways, and the user must be instructed in the advantages and disadvantages of each alternative file structure for his intended application. All users must be certified by the Department of Geography and given "hands-on" terminal experience before they can use the system, but users are also urged to purchase the DIGIT SERIES USER'S MANUAL (Ericksen, 1978), which gives detailed instructions on how to use the software packages. Video tapes are also provided which students can view in lieu of short courses or orientation sessions.

A second problem which has endured is the operating efficiency of the software and data base organization. A particularly important consideration in data base design is to store the data so that they can be used for a wide variety

of applications and so that the way they are used can be changed quickly and easily -- this is especially important in an interactive environment. Programming for small-core, real-time systems forces many compromises between file structures and operating efficiency. In order to make this trade-off, however, the file structures have to be open-ended and designed for display efficiency. The digitized file structure is well-suited for graphic display on the CRT, since the data are stored in strings in the same fashion as formatted by the IMLAC, but this file structure is not always the most efficient for geographic information systems. The scaled file, for example, stores the same information as the digitized file but the strings are scaled to real numbers for tic mark registering, rotation, map rectification, and other scaling functions.

A third problem is system support. Currently, DIGIT SERIES software is not documented fully enough to be supported by the University Computer Center staff. Measures are being taken to ensure that continuing staff have the experience to continue development and support of the software.

A fourth problem is budgetary: finding the resources in a university to financially support the growing use of a specialized computing facility. Both the cost of computer and staff time will increasingly burden the Geography Department and/or the University Computer Center as more

users are introduced to the system. The development of an interactive digitizing and graphics system poses a number of institutional problems in an educational environment. Instructional systems rely heavily on a traditional instructor-student format and budgets and staffing are not generally geared to supporting hardware and software systems for specialized instructional systems.

A fifth problem is the lack of testing of DIGIT SERIES modules with large projects. The system has been developed at a rate exceeding users who have exercised the various options. Occasionally, constraints are encountered which require modification for efficient operation.

Finally, the problem of transportability has become apparent as other institutions with different hardware configurations and programming languages request copies of the software. This is a problem we have yet to deal with. Given our unique hardware configuration, improving transportability will be difficult.

CONCLUSION

Unlike most existing systems which force all applications into a single mode of data structure, and in some cases require that data be captured in a particular way and at a specified scale, the DIGIT SERIES has been designed to store graphic elements in a way in which changes can be made with ease. The ability of converting from one file structure to

another allows capturing the data in the most convenient form, given the initial character of the digitized data, and converting the data to the most appropriate form for analysis. Being interactive and executed in a conversational mode, the DIGIT SERIES has also proved to be a valuable educational tool by linking student generated maps with data and by providing the means for developing analytical skills necessary for solving geographic problems.

Now that the design and implementation of the digitizer-graphics system has been accomplished, the process needs to be evaluated and a design of the next system begun. The whole process should be considered a learning exercise from which a better system would emerge. In other words, we take pride in the system but there may be things that we would do differently.

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